



## **Pilot Demonstration of Alarm Management in Oil & Gas Operations. - Decision Support from Functional Modelling.**

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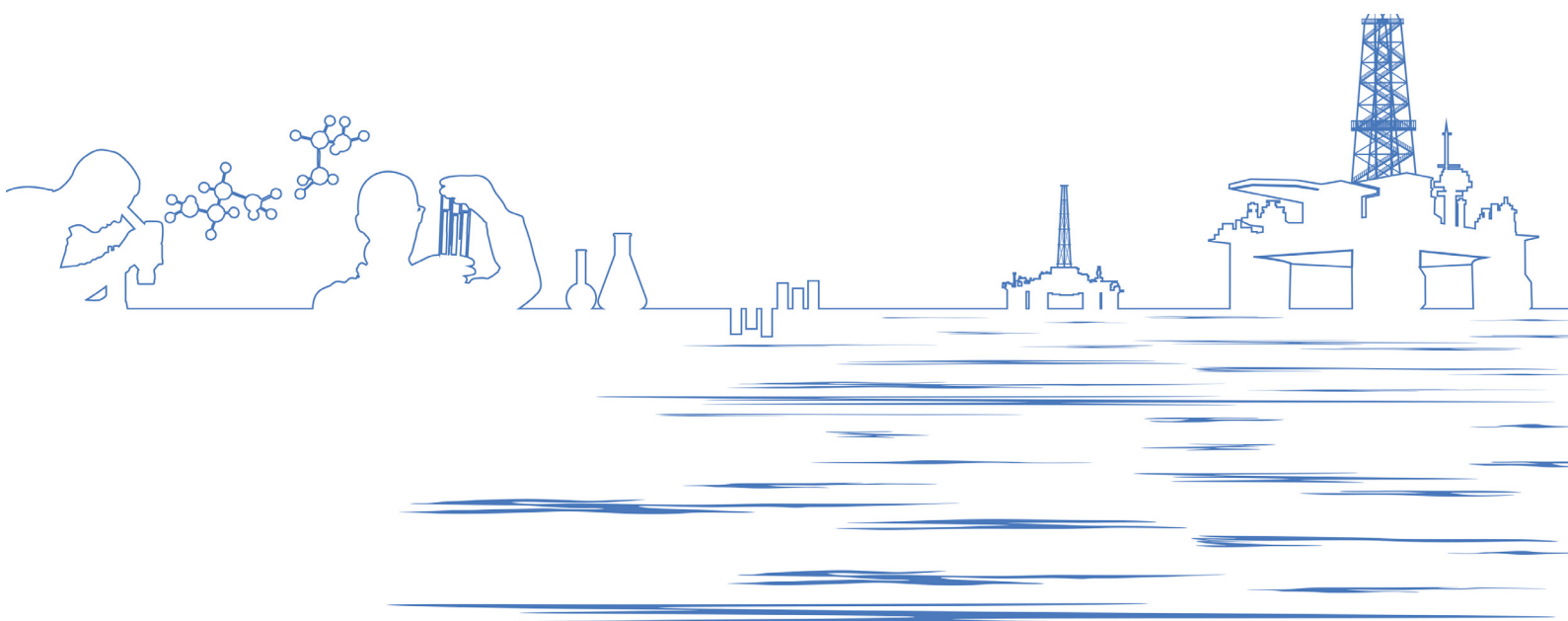
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# DHRTC Research

## Abstracts



# Danish Hydrocarbon Research and Technology Centre Technology Conference 2017

## Emulsion Formation for EOR Applications

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### Summary

There is a high demand for novel enhanced oil recovery (EOR) methods to recover more oil from the existing petroleum reservoirs due to depleting oil and gas resources worldwide. Application of nanoparticles (NP's) for EOR is an emerging technique amongst others e.g., low salinity water flooding, microbial, and SmartWater flooding. These methods reported wettability alteration as the main mechanism behind increased oil recovery. Formation of water-soluble oil emulsions in the presence of insoluble fines has also been reported as a possible working mechanism. This work presents emulsion formation in brine-oil systems in the presence of calcium carbonate ( $\text{CaCO}_3$ ) NP's. The effect of size of NP's and brine salinity on emulsion formation were also studied.

Oil phase consisted of either one of the two model oils (decane (D) and hexane-hexadecane (HH) mixture of 1:1 vol. ratio) or North Sea crude oil (NSCO) from South Arne platform. Brine phase consisted of deionized water (DIW) and synthetic seawater (SSW), mimicking the composition of North Sea water.  $\text{CaCO}_3$  NP's of three different sizes of 15-40, 50, and 90 nm were used. Emulsion formation in brine-oil-NP's systems was tested by using a commercially available sonication equipment, Branson Sonifier® SFX250. All the experiments were performed at room temperature for the same conditions of 5 minutes of ultrasonic processing by using a 6.5 mm tapered microtip (sonication probe) with an output power of 30 W. Emulsion characterization (emulsion droplet size) was performed with an optical microscope (Axio Scaope.A1) and Transmission Electron Microscopy (TEM) was used for characterization of NP's.

Emulsion formation was tested in different brine-oil-NP's combinations. DIW-D formed a large amount of emulsion in the presence of 15-40 nm  $\text{CaCO}_3$  NP's; almost all water and oil emulsified. The amount of emulsion formation decreased with an increase in the size of NP's from 50 to 90 nm. The emulsion formation trend in DIW-HH-NP's was similar to that of DIW-D-NP's. However, the former combinations formed comparatively less amounts of emulsions for 50 and 90 nm NP's. SSW combination with D and HH formed very large amounts of emulsions upon sonication with 15-40 nm NP's, similar to that of DIW-D/HH. The emulsion formation trend decreased for 50 nm NP's and almost no emulsion formation for 90 nm NP's in both the combinations of SSW-D and SSW-HH. NSCO sonicated with DIW and SSW almost completely emulsified for all the NP's sizes (15-40, 50, and 90 nm). A decrease in amount of emulsion formation was observed with an increase in the size of NP's for all the cases of DIW/SSW-model oils. Similarly, emulsion characterization showed relatively smaller emulsion droplet sizes (better emulsion stabilization) for small sized NP's. Brine salinity showed significant effect on emulsion formation i.e., emulsion formation increased with a decrease in brine salinity.



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## Decoding the Water Flooding Processes from Produced Water Composition

### A Case Study from the Halfdan Chalk Oil Field, Danish North Sea

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Analysis of produced water is one of few direct sources of information to the subsurface processes active in an oil field. However, revealed geochemical patterns are typically complex and require a multidisciplinary approach to successfully unlock and decode. The Halfdan field initially contained two main types of formation brine but now, after 15 years of extensive water flooding, the field contains mostly a seawater modified type. The initial water was a low salinity sulphate-depleted type and a medium high saline sulphate-rich type that varied in a geographically systematic manner. The water treatment resulted in a net deposition of sulfate and Mg and a net export of Ca and Cl ions from the field. This pattern is similar to core flooding results, suggesting that a substantial alteration of the wettability of the chalk occurred. Spatial and temporal variation in water composition are mapped based on 3880 analysis from 75 wells and are related to water flooding history and sweep efficiencies obtained from 4D seismic. Produced water analysis is thus an important asset for designing water sweep in mature fields. Furthermore knowledge about the initial water types may optimize water treatment and prediction of geographically distribution scale and corrosion risks.

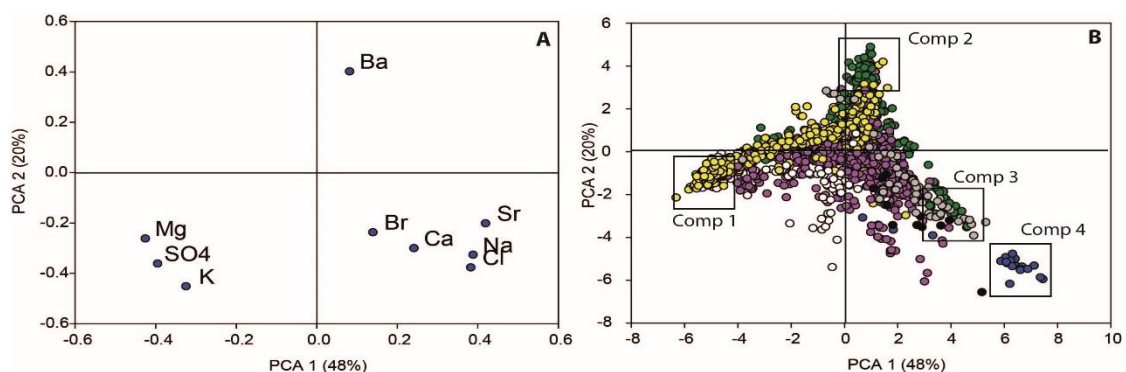


Figure 1. Illustration of the PW composition on Halfdan exhibit transitional compositions between 3 end-compositions (1-3). Kraka (blue) is a composition 4. Intra Halfdan variation (yellow, green pink) reflect geographical position with respect to the present day crest structure of the field.

## **EXPERIMENTAL STUDY OF THE SHORT –AND LONG TERM BEHAVIOUR OF THE RJD LATERALS UNDER STATIC AND DYNAMIC RESERVOIR CONDITIONS**

*Medetbekova M.K., Salimzadeh S., Christensen H.F, and Nick H.M.*

For efficient hydrocarbon production, creating a direct connection between the reservoir and the wellbore that extends the reach of the wellbore laterally, and bypasses the damaged area is crucial in improving the productivity of the wells and enhancing the swept area. This has become feasible by a new technology called Radial Jet Drilling (RJD) technology, in which, relatively long, small-diameter laterals can be jetted radially from the main wellbore. However, the success of this technology very much depends on the long-term stability of the laterals under dynamic reservoir conditions. In this study, a set of sophisticated laboratory experiments are designed and performed on two distinct outcrop chalks from Austin (US) and Welton (UK) that are analogue to the reservoir chalk in the North Sea. Experimental results from the tested samples are analysed to extract the static and dynamic strength properties of the rock.



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## Porosity effects of electrostatic forces in saturated mineral powders

Leonardo T. P. Meireles, Einar M. Storebø and Ida L. Fabricius

Electrostatic forces acting at the particle scale can be an important drive behind water weakening of chalk. Upon the replacement of oil with brine, ions present in the imbibing brine can exchange with ions already adsorbed to the calcite surface, potentially leading to a change in the electrostatic potential.

Depending on the composition of the brine, this can cause an increase in the disjoining pressure between particles, thereby either reducing the cohesion of particles connected via contact cement or decreasing friction between free particles (Figure 1). Assessment of these forces is mostly done through modelling of a Gouy-Chapman electrical double layer using the Debye-Hückel approximation, but their effect is difficult to predict.

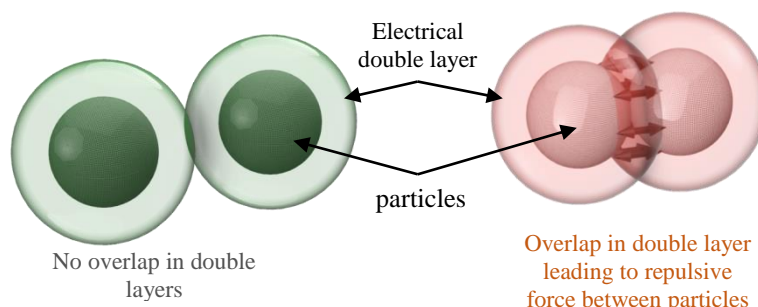


Figure 1 – Repulsion between solid particles caused by the interaction between their respective double layers.

In this paper, we assess the effect of electrostatic forces by measuring pore-water effects on porosity in sediment columns by using low field Nuclear Magnetic Resonance Spectrometry (Figure 2). Samples of Calcite, Quartz or Kaolinite powder were saturated with brines containing ions found in seawater ( $\text{Na}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$ ) at varying ionic strengths and as a non-polar reference, with ethylene glycol. The difference in porosity between a sample saturated with ethylene glycol and a sample saturated with a given brine reflects the repulsive pressure resulting from the electrostatic forces. We found that for calcite samples, saturation with solutions containing divalent cations ( $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ) lead to higher repulsive forces between the grains, while adsorption of  $\text{SO}_4^{2-}$  counteracts the initially positive surface charge, leading to a decrease of the repulsive forces. For Kaolinite and Quartz, both surface charge and ionic strength have effect on porosity. For kaolinite, differences in potential between the silica and alumina faces as well as the edges can either lead to repulsion between particles or to flocculation depending on ionic strength and ionic species of the fluid. The results indicate that low salinity water flooding may lead to the mobilization of kaolinite within oil reservoirs. For quartz, relatively high porosity for powders saturated with sodium chloride brine indicates that  $\text{Na}^+$  is a potential determining ion for the quartz surface.

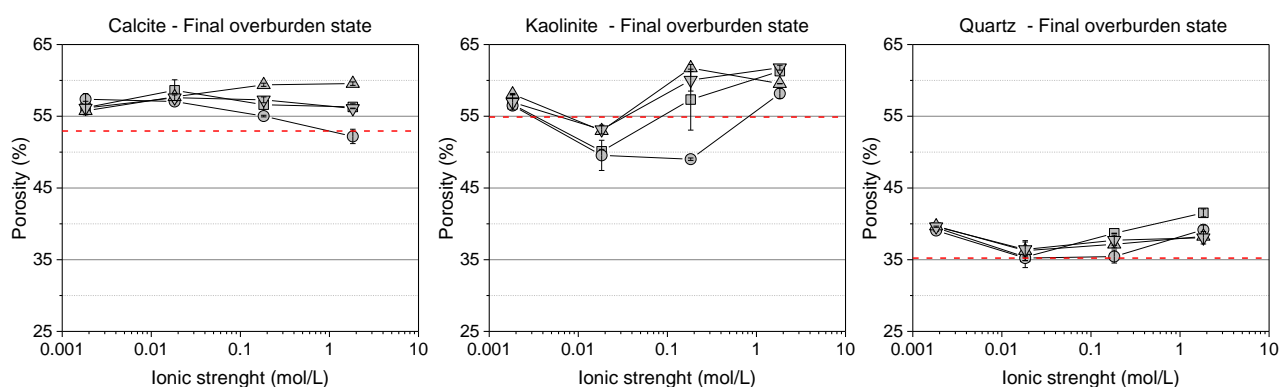


Figure 2 – Critical porosity of mineral powder column (Calcite samples overburden = 31MPa \*, Kaolinite and quartz = 49MPa\*). Brines are  $\text{CaCl}_2$  ( $\Delta$ ),  $\text{MgCl}_2$  ( $\nabla$ ),  $\text{Na}_2\text{SO}_4$  ( $\circ$ ), and  $\text{NaCl}$  ( $\square$ ). Symbols indicate mean of two measurements (in two distinct samples). The reference line (red, dashed) represents the average between two porosity measurements of samples saturated with ethylene glycol.

\* Reference pressure = 1 atm.



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# Danish Hydrocarbon Research and Technology Centre Technology Conference 2017

## **An integrated experimental approach to quantify the oil recovery potential of seawater and low-salinity seawater in North Sea chalk oil reservoirs**

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*Danish Hydrocarbon Research and Technology Centre, DTU, 2800 Kgs. Lyngby, Denmark*

### **Abstract**

In this study, the oil recovery potential of Smart Water in the Danish sector of the North Sea chalk reservoirs was investigated. A series of flooding experiments were conducted at reservoir conditions, and a spontaneous imbibition test was carried out at reservoir temperature. Reservoir cores were used along with crude oil samples from the North Sea and representative synthetic formation water. The effect of changing the salinity, concentration of potential determining ions and temperature was studied as potential Smart Water effects. Of the investigated fluids, injection of low salinity seawater gave the highest additional oil recovery.



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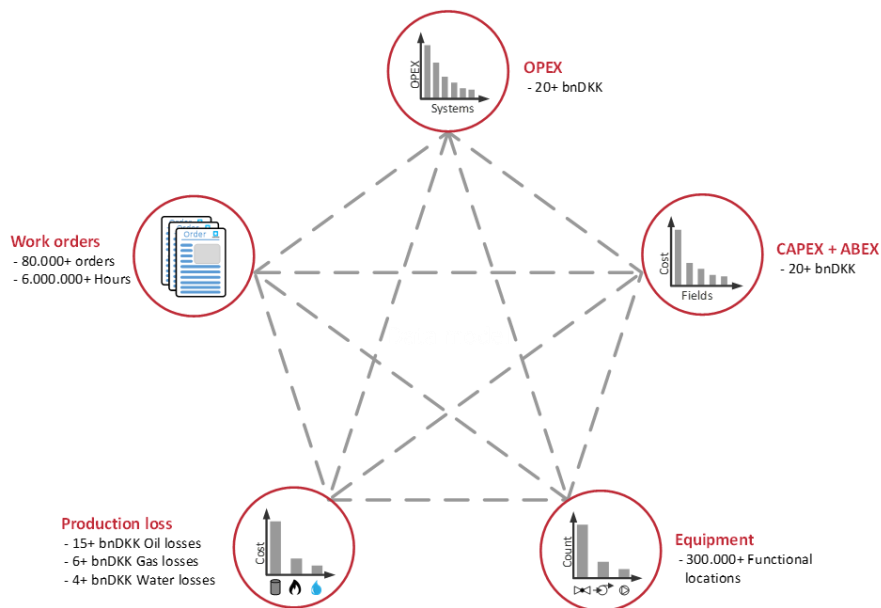
# Danish Hydrocarbon Research and Technology Centre Technology Conference 2017

## Fact based optimization of maintenance

### Utilizing operational data to optimize planning and execution of maintenance

*Niels Henrik Mortensen, Professor, DTU Mechanical Engineering*  
*Andreas Proschowsky, Research Assistant, DTU Mechanical Engineering*  
*Kim Bo Kristiansen, Research Assistant, DTU Mechanical Engineering*  
*Giacomo Montagner, Research Assistant, DTU Mechanical Engineering*  
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Throughout time, large quantities of operational data have been gathered for maintenance of topside facilities in DBU. The reporting and structuring of the data has however varied significantly over time and between assets and systems. This has complicated the use of the data to support planning and optimization of maintenance. This study has investigated how different maintenance activities can be compared and how data can be cleaned and restructured to support planning and optimization. The result is a data model developed in QlikView that quickly enables comprehensive analyses of cost and time consumption of maintenance of topside systems and equipment types. This presentation will present the challenges of using historical maintenance data, the development of the data model and discuss its application areas.



# Danish Hydrocarbon Research and Technology Centre Technology Conference 2017

## Experimental investigation on the effect of seawater ingress on the corrosion behavior of production tubings

*Riccardo Rizzo; Ajit Murli Rao; Rajan Ambat*

Corrosion and scale have a very important impact on the petroleum industry. On one side, they constitute a significant part of the capital and operational expenditures (CAPEX and OPEX), whereas on the other side they compromise the health and safety of the field personnel as well as the environment. It has been estimated that corrosion and scale formation account for 25% of the operational safety incidents, 8.5% increase on CAPEX and 11.5% increase to the lifting costs.

CO<sub>2</sub> corrosion occurs when water is present in the system and it wets the steel surface. A certain amount of water, *formation water*, is always present in the reservoir and enters the production tubing when the well starts to produce. In addition, it is normal practice to pump sea water from an adjacent injector well in order to maintain the reservoir pressure and drive oil out of the formation. This technique is known as *waterflooding*. As the field ages, the water/oil ratio can increase and reach level of 95% or higher leading to more significant corrosion problems. Another downside of producing water from an oil field is the precipitation of scale. Scale can deposit on the wall of production tubing decreasing the inner diameter of the pipe reducing the production rate.

In order to investigate the effect of the *Seawater (SW) fraction* as a fraction of the produced water a conventional three -electrode electrochemical cell setup was used. The atmosphere constituted of gas mixtures of pure CO<sub>2</sub> and 100ppm H<sub>2</sub>S in CO<sub>2</sub>. The sample investigated were equivalent grade of L80-1Cr and L80-13Cr. The composition of the seawater and formation water were taken from Halfdan and they were mixed in the following ratio: 0% SW, 50% SW and 100% SW. Three different temperatures have been tested, namely: 40°C, 60°C and 80 °C. Experiments were conducted under initial pH of 6.1 and 3.9. The corrosion products and precipitates were analyzed using Grazing Incidence XRD, SEM-EDS and FIB.



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## Systematic investigation of scales and corrosion on production tubings

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Internal corrosion of pipelines occurs extensively in the oil and gas production. The corrosive environment is composed of formation water, injection water, the dissolved acidic gases, such as  $\text{CO}_2$ , volatile organic acids, and the hydrocarbons. Being the most commonly used construction materials for pipelines, carbon steels are prone to corrosion in such corrosive environments. In particular, localized corrosion i.e. pitting corrosion and mesa attack occurs in conjunction with the formation and removal of corrosion scale in the  $\text{SO}_4^{2-}$  and  $\text{CO}_2$  containing produced water. Localized corrosion or underdeposit corrosion attack usually occurs due to porous nature of the scale or once the protective scale is damaged locally, and constitutes a principle cause resulting in the failure of the pipelines. Therefore, scale formation affects the corrosion behavior of the pipeline materials by changing the morphology and the physiochemical properties of the surface layer. Scale precipitation not only causes corrosion damage to the pipelines, but can also cause formation damage in the reservoir, flow loss or blockage on flow lines and equipment's energy leak and severe accidents, which can influence the safety of production and the economic benefit of petroleum industry. Scale deposit precipitate out as a mixture of different elements, which may occur when solution becomes saturated due to the change in temperature, pressure, pH or due to mixing of two incompatible fluids. Severe scaling occurs when formation water rich in various compounds such as  $\text{Ca}^{2+}$ ,  $\text{Sr}^{2+}$ ,  $\text{Ba}^{2+}$ ,  $\text{Mg}^{2+}$  ions etc mix with the  $\text{SO}_4^{2-}$  rich sea water, causing super saturation. Scale deposition products in oil and gas field are mainly consisted of calcium carbonate, calcium sulfate, barium and strontium sulfate and carbonates, iron, silicon sediments and other insoluble solids.

This paper focus on detailed systematic investigation of the scales and corroded internal surface of the tubes with scales to understand the nature of corrosion and scales formed under various well conditions. The experimental work include visual observation and digital photography of the interior surface of the tube and scales which is horizontally split, high resolution scanning electron microscopy, cross-section analysis using metallographic preparation and focused ion beam (FIB) cutting, EDX and X-ray mapping, Transmission electron microscopy, and X-ray diffraction for phase analysis. Corroded tubes and scales from three different fields were analysed namely Halfdan, Dan, and Gorm. From each field and well, tubes were selected based on the depth to provide systematic evaluation starting from shallow depth to high depth levels. Tubes from shallow depth showed high amount of penetration and localized attack compared to low uniform corrosion observed in tubes from higher depth. The scales showed a layered structure showing different compounds explaining the corrosion and scaling, based on the history of the well. Analysis of scale formed in tubes at shallow depth comprised predominantly of iron and calcium carbonate with high amount of chlorine present within the scale. The scale initially start to grow as iron sulfate/sulfite porous layer, attributing to higher localized corrosion attack observed in these tubes from shallow depth. The scale formed in Gorm and Dan at higher depth were very thick and dense and comprised of barium and strontium sulfate with high amount of calcium and chlorine present within the scale. The morphology and structure of the scale becomes porous with the presence of chlorine and may cause localized or underdeposit corrosion attack, if present in the scale closer to the pipe surface.



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## Kinetics of Scale Formation in Oil and Gas production

*Petter Lomsøy*

Scale formation poses a major challenge for the oil and gas industry. Scale build up on interior piping may cause losses in production, due to loss in internal diameter. Substantial deposition may result in stop of production or failure in critical components.

Enhanced understanding of scale behavior is essential for ensuring the integrity and efficiency of wells, pipelines and facilities. By studying the kinetics of scale formation, the objective is to create a knowledge base for further model development. Improved prediction of scale occurrence, will contribute to optimal recovery of oil reserves in the future.

This project aims towards the study of  $\text{FeCO}_3$  scale, which are commonly found in the North Sea. A comprehensive experimental study are to be conducted, validated by measuring the kinetics of  $\text{CaCO}_3$ , and compared with values reported in literature. After validation, the measurement of  $\text{FeCO}_3$  scale kinetics may proceed. Enhanced understanding of the properties of the scale in question, will be valuable for the work on avoiding scale deposition.

Planning of an experimental campaign, for measurement of surface deposition kinetics, are to be commenced. The deposition rate are likely to be measured as a function of pressure, temperature and level of supersaturation.

Earlier studies conducted at CERE, has included the physical properties of scales such as solubility. The focus on this project are moving towards prediction of the operating conditions, which causes the formation of scales.

By enhanced understanding of the conditions, which facilitate surface deposition, an active control of well properties may be introduced. This would be a method for avoiding/limiting the scaling problem. The possible savings in cost are substantial, both within maintenance and down time.

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## **Spatial distribution of silica in Danian chalk onshore Denmark – towards an improved understanding of the Ekofisk Formation as a reservoir**

*Kasper Høj Blinkenberg<sup>1</sup>, Kresten Anderskov<sup>2</sup> and Lars Stemmerik<sup>1</sup>*

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Silica has long been recognized to influence reservoir performance in the Danian Ekofisk Formation in the Danish North Sea chalk fields. Recent studies indicate a stratigraphic control on the silica distribution across the Danish Central Graben, with maximum concentrations in the middle Danian. However, the density of cored wells across the region provides poor spatial resolution, and the more detailed architecture of the silica and its influence on reservoir properties is therefore still poorly understood.

In this study we present detailed sedimentological, ichnological, diagenetic, bulk geochemical and isotope data from the middle Danian chalk in Dalbyover Quarry, Northern Jutland. The distribution of silica, which is very different from that seen in Maastrichtian chalk, and the outcrop is currently believed to form an analogue for offshore silica-enriched intervals of the Ekofisk Formation. The dataset will help to better understand the small scale 2D reservoir architecture of the Danian Ekofisk Formation.



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## Fracture Characterization and Modelling in the Kraka Field

*T.M. Aabø, M.J. Welch, J.S. Dramsch, M. Lüthje, S. Seyum, F. Amour and C. L. Würtzen*

*Center for Oil and Gas – DTU*

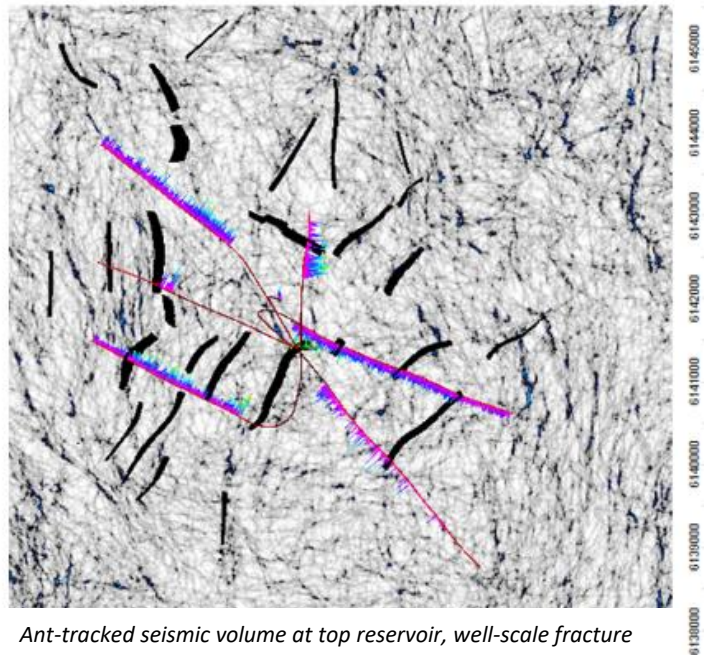
The Kraka Field is an anticlinal structure induced by halokinesis, located in the Danish Central Graben. It is produced through depletion of the naturally fractured Ekofisk Formation of Danian age, which is a widespread chalk reservoir offshore Denmark.

The Kraka fracture pattern has been mapped through borehole images, core- and seismic data prior to upscaling and fracture modelling. Two main fracture trends were identified in the Ekofisk Formation. The first is a NNE/NE trending regional fracture set, which has consistent orientation across the Kraka structure. This trend is parallel or near-parallel to the main fault system, mapped through 3D seismic interpretation, which aligns with the local maximum horizontal stress. The second set consists of fractures trending parallel or perpendicular to contours of the Kraka dome. This fracture set is therefore thought to have formed during halokinesis, and it is expected to follow the strain evolution of the Kraka chalk. Both sets occur as fracture swarms and as isolated features.

High resolution lineations mapped on two ant-tracked cubes (generated through RGB-image processing of the 3D seismic volume and through a variance cube, respectively) shows a good correlation with the well-scale fracture trends and with the structural framework in Kraka. Moreover, an additional structural trend related to the domal structure was identified in the lineations: shallow dipping faults ( $<30^\circ$ ) dipping away from the contours of the dome. These faults are likely related to an E-W compressional event, which occurred during inversion phases in the Late Cretaceous evolution of the Central Graben.

Localized variations in the fault pattern occur due to re-activation of older, Mesozoic structures.

The Kraka fracture pattern established during the reservoir characterization of the field was successfully reproduced in terms of main orientations in an industry-standard discrete fracture network model (DFN). Resultant fracture parameters (e.g. apertures and length), are however associated with a larger degree of uncertainty. This demonstrates the need for geomechanically based DFNs, to achieve an improved understanding of the fracture distribution in the chalk reservoir.



*Ant-tracked seismic volume at top reservoir, well-scale fracture densities (purple) and structural framework (black).*



## **OUTCROP ANALOGUE ON THE MAASTRICHTIAN CHALK OF STEVNS KLINT, DENMARK: AN INTEGRATED APPROACH BETWEEN HIGH RESOLUTION SEISMIC, GEOLOGY AND PHOTOGRAMMETRY**

*Mattia TAGLIAVENTO(1,2,@), Janina KAMMANN(2), Lars STEMMERIK(1,2), Lars NIELSEN(2), Alireza MALEHMIR(3)*

*(1) Natural History Museum (Denmark) (2) University of Copenhagen (Denmark) (3) Uppsala University (Sweden) (@) mtagliavento@snm.ku.dk*

Modelling of chalk from an oil production perspective represents a large challenge due to the sudden changes of petrophysical properties, related to factors like microfabric variation, silicification and clay content. The problem cannot be addressed thoroughly by core sampling and offshore seismic mapping because limitations in seismic resolution and availability of rock samples. Therefore, we have developed an approach that relies on detailed investigations of onshore reservoir analogous rocks where seismic acquisition can be combined with data collection in adjacent cliff or quarry surfaces. The well-exposed, coastal cliffs of Stevns Klint, Denmark constitute a perfect location to directly correlate high-resolution seismic data with the geological and petrophysical information of the chalk due to the possibility to sample vertically and horizontally along the cliff. Parallel to the cliff, we have acquired two 500 m long high resolution seismic lines using both P and S-wave acquisition techniques. Furthermore, we collected samples from the cliff walls that were investigated in order to describe the microfabric with the Scanning Electron Microscope (SEM) and obtain petrophysical information. Due to the narrow beach present and the hanging blocks of rock over it we used photogrammetry methods to do the interpretation of the outcrop architecture.



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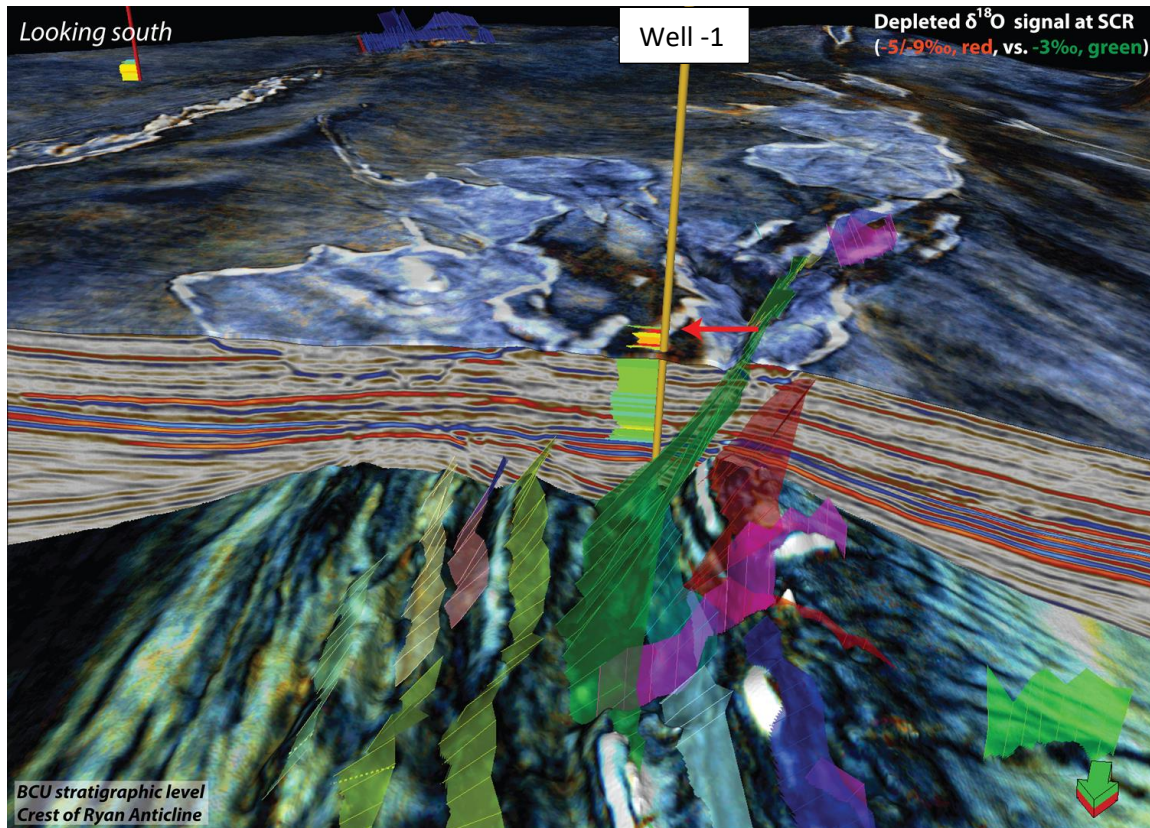


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## Fluid migration through the Chalk Group: examples from 3D seismic data

Florian Smit, Frans van Buchem, Mikael Lüthje, Lars Stemmerik

Fluid expulsion is a key element of the petroleum system, and is mostly simulated with basin modelling software as a function of depth and temperature. Direct indicators of fluid migration are not readily available, yet can provide important insights in timings of the fluid expulsion system and impact on reservoir quality. Here we present direct evidence for large-scale fluid migration from 3D seismic data: 1) during deposition of the Chalk Group in the Late Cretaceous and Danian, and 2) post-chalk ascending diagenetic fluids altering the porosity of the chalk (Figure 1). Two case studies will illustrate how fluids have interacted with the chalk leading to different reservoir properties at present. It demonstrates the usage of 3D seismic data integrated with petrography and geochemistry, to further our understanding of fluid migration pathways of both basinal fluids and hydrocarbons.



**Fig. 1** Staircase diagram with 3D visualization of the integration methodology. Shown are two stratigraphic levels (BCU and near top Tor Formation) with spectral decomposition, mapped fault planes, and  $\delta^{18}O$  for the Chalk Group in O-1X. Where the bright anomaly reaches O-1X, material from that interval, more depleted  $\delta^{18}O$  are observed (1925 m, red arrow). Figure from Smit *et al.* (under review)

Smit, F.W.H., van Buchem, F.S.P., Holst, J.H., Lüthje, M., Anderskov, K., Thibault, N., Welch, M., Stemmerik, L. (under review)  
*Seismic-scale porosity variations of diagenetic origin controlled by fault-related fluid migration (Upper Cretaceous Chalk, Danish Central Graben, North Sea Basin), Basin Research*



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## **Evolution of the petrophysical and geomechanical chalk properties along a water- to hydrocarbon-bearing transect of a reservoir and impacts on production-related rock deformation (Kraka Field).**

*Amour Frédéric*

Studies on chalk reservoirs and their outcrop analogues have identified the mineralogy, compaction, recrystallisation, and cementation as major parameters controlling the range of values and spatial distribution of petrophysical and mechanical properties of chalk in subsurface. The degree of influence of each parameter on reservoir properties is case-dependent and related to the depositional conditions and the evolution of effective vertical stress and type of fluid present in pore space during burial.

The present study focuses on a 100 m-thick transect from base to top of the Kraka reservoir and encompasses the Tor and Ekofisk Fms. The aim is to distinguish the particular effect of deposition conditions, water saturation and changes in effective stress on the petrophysical and geomechanical properties of chalk across the reservoir. Production-related changes in effective vertical stress is also estimated to assess reservoir deformation due to pressure depletion. Based exclusively on subsurface data, we use visual inspection of cores, well correlation, back-scattered electron microscopy (BSEM), X-ray diffraction (XRD), X-ray fluorescence (XRF) and well log analyses to provide information on the rock fabric, lithology, and stratigraphy. Mechanical properties values of chalk are derived from iso-frame conceptual models and triaxial test results, and fluid pressure data are used to estimate *in situ* effective vertical stress.

Well correlation indicates that low porosity intervals referred to as dense zones, are intercalated with and laterally grade into high porous intervals across the reservoir. Dense zones display an average of 20% porosity decrease and a 30% to 50% increase in dynamic Young's moduli values compared with adjacent porous intervals. On the one hand, the decrease in porosity values is correlated with an increase in non-calcite residue from 9% to 23% (clay and quartz) and likely results from changes in deposition conditions with dense zones recording periods of high runoff and low sedimentation rate. On the other hand, the stiffening of dense zones results from an increase in chalk lithification and quartz cementation taking place shortly after deposition and during burial. In addition, hydrocarbon charging impacts differently the diagenesis of chalk along a vertical transect of the reservoir. Increase in water saturation from top to base of the reservoir seems to enhance calcite cementation, thus, reducing porosity, whereas overpressure towards the top of the reservoir inhibits mechanical and chemical compaction, thus, preserving porosity.

Although triaxial tests are carried out at a 4MPa confining stress, which can represent an underestimate of the *in situ* horizontal stress, comparisons between changes in effective vertical stress over production time and results from triaxial tests provide crucial information on past and current chalk deformation. Pressure depletion over a 25 years production history led to brittle deformation of high porous chalk compartments initiated between 1991 and 1997. Identifying petrophysical and geomechanical compartments in a reservoir and investigating deformation behavior of each compartment during production will help with predicting the evolution of flow properties over the field's lifetime at a reservoir scale.



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## THE SELF-HEALING CEMENT PROJECT: FIXING CRACKS IN DEEP SUBSEAFLOOR CONCRETE STRUCTURES

*Kasper U. Kjeldsen, Alberto Scoma, Søren D. Nielsen, Zhenguo Shi, Jørgen Skibsted, Hans Røy*

The Self-Healing Cement project investigates the feasibility of a microbially-based self-repairing cement biotechnology at deep-subsurface conditions. This relies on developing novel cement formulations with embedded carbonate-precipitating bacteria able to fix cracks forming in cementitious structures due to mechanical stress. The project has two primary objectives: (i) to determine the complex interplay between microbiology and chemistry controlling the formation and stability of  $\text{CaCO}_3$  crystals in subsurface environments; (ii) to use this knowledge to develop a self-healing cement formulation for offshore oil wells. These objectives are tackled from a basic and applied research perspective. The former is delineating the physiological limits for microbial life under the multiple extremes featuring reservoir-cement environments, e.g., pH above 10, temperature above 50°C and high hydrostatic pressure (HP). We collected a number of spore-forming bacterial isolates and initiated an intense growth screening. Our preliminary data indicate that bacterial cultures are able to grow consistently at pH 10, 60°C and 30 MPa. Tests on pH values up to 12 suggest this to be the most limiting factor, which impacts cell's morphology and activity. The applied research approach aims at embedding bacteria into cement formulations (e.g., through superabsorbent polymers) while allowing microbial activity. Preliminary data indicates that bacterial spores are able to germinate, grow and precipitate  $\text{CaCO}_3$  when cultivated both in liquid suspensions and embedded in the polymer, with successfully tested conditions up to 50°C, pH 10 and atmospheric pressure. A thermodynamic model of the self-healing capacity of such novel cement formulations is foreseen. The presentation will introduce the project's background and highlight key results.



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## Risk based inspection planning for sub-sea well integrity management

*Simona Miraglia*

Risk based inspection planning (RBI) is widely applied for the asset management of critical infrastructures, from transportation infrastructures and pipelines networks, to offshore structures such as platforms and wind turbines, representing a very powerful tool to estimate the best maintenance strategy to extend the lifetime of infrastructures. Therefore, in the context of sub-sea well integrity, RBI method represents the best choice tool when aiming at reducing workovers and OPEX expenditures.

The RBI method takes basis in classic Bayesian decision theory, whose scope is to give a structured and mathematically consistent tool to screen among different decision alternatives in order to find the optimal management strategy which maximizes the utility (or equivalently minimizes the costs) over the life cycle of the asset.

In order to investigate the feasibility of RBI approach for subsea wells, a system identification and risk screening workshop has been held at DHRTC to define a baseline for the system boundaries identification, components taxonomy, failure mode of critical components, dependency among failure (dependency factsheet, cascading) and critical deterioration mechanisms currently affecting the performance of sub-sea wells. An important outcome of the workshop was the need of improving knowledge on prediction models, mapping, characterization and quantification of uncertainties, reliability of inspection tools and effectiveness of corrosion and scale mitigation methods for sub-sea wells along with cost associated to those interventions. Further research is ongoing with the aim of improving knowledge on the aforementioned critical elements in order to build and calibrate a model for risk based inspection planning using Bayesian probabilistic networks.



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## **Structural Monitoring for Offshore Structures: A challenge needs to be undertaken**

*Authors: Evangelos Katsanos, Sandro Amador and Rune Brincker*

### Abstract:

Offshore Structures, including the widely used steel platforms related to the Oil and Gas industry as well as the wind turbines, are constantly exposed to a multi-hazard environment that threatens their structural integrity and may question their functionality even until the end of the designed lifetime. Stormy conditions and extreme waves can impose high risk for extensive structural failures, while various deterioration mechanisms, such as the corrosion and scaling commonly observed for structural members at marine environment, may degrade substantially the available capacity of the offshore structures. Therefore, none reliable decision can be reached regarding the current and future (either short-or-long term) operation and survivability of the offshore structures unless a deep and precise comprehension of their dynamic performance is robustly available. Such valuable information about the structures' current condition (i.e., health) is expected to enable: (a) assessing with increased accuracy the existing capacity, (b) predicting the remaining life-time, (c) undertaking interventions (if necessary) to extend the life-time and (d) scheduling maintenance strategies of high efficiency and reduced cost. Along these lines, the Structural Monitoring project, initiated within the framework of the DHRTC multi-dimensional portfolio, embraces a large variety of research activities aiming, via the utilization of the actual dynamic response measurements, to identify reliably the condition of the offshore systems and estimate the stress-and-force states of different structural members. The latter two objectives, facilitated by contemporary identification techniques (e.g., Operational Modal Analysis) and advanced numerical modelling, constitute the necessary ingredients for launching a successful Structural Health Monitoring campaign that, in turn, will allow for efficient structural integrity and reliability management.



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## OMA based Strain Estimation in Friction System

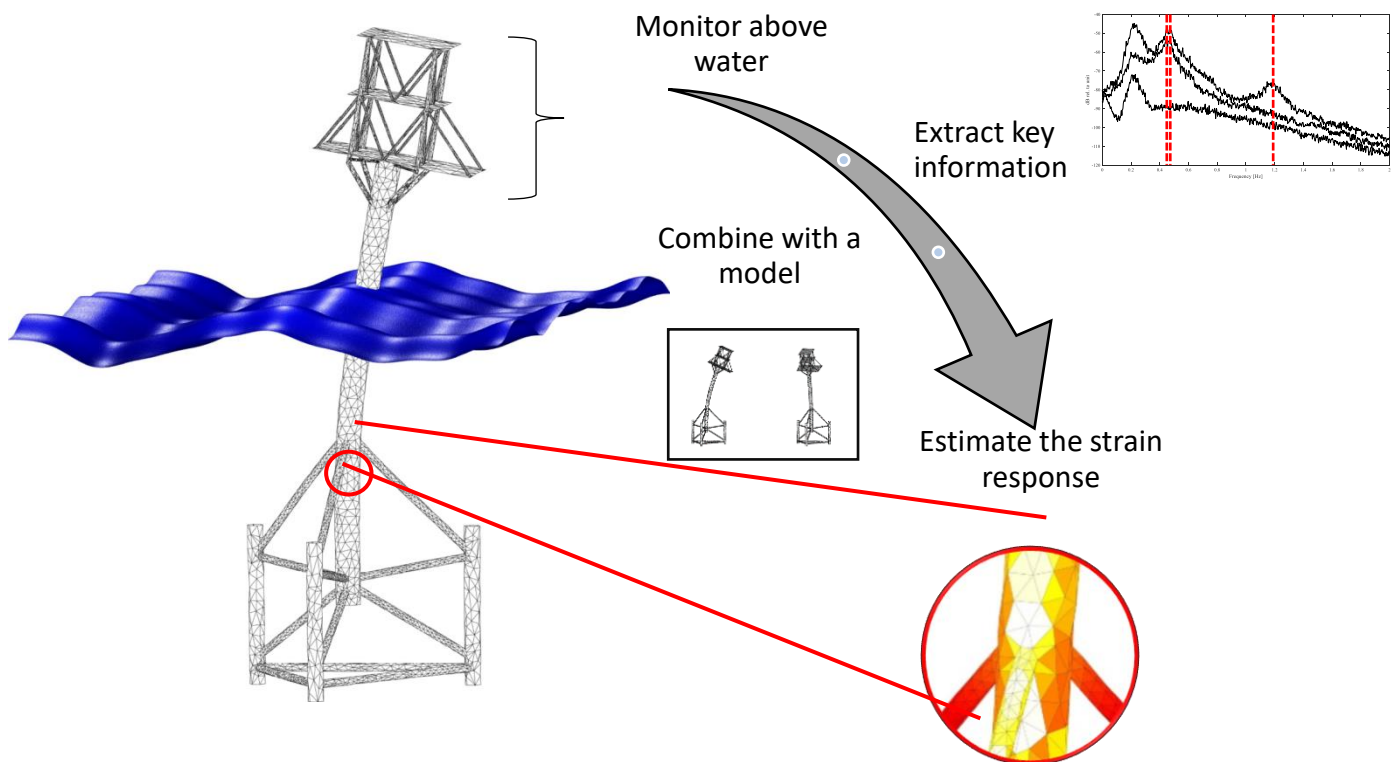
### Numerical Application on Scale Model of Offshore Platform

*Marius Tarpø, Tobias Friis, Bruna Nabuco, Sandro Amador, Evangelos Katsanos, Rune Brincker*

It is possible to estimate the strain response of a structure in unmeasured points by the use of operational modal analysis and modal expansion. However, both techniques are based on the assumption that the system is linear. But this is not always the case since nonlinear elements often violate this assumption - like friction between offshore platforms.

In this presentation, we investigate the precision of estimating the strain response of a scaled offshore platform using the operational response of a numerical simulation where we introduce nonlinearities by adding friction to the platform. In this experiment, we find that this approach of strain estimation can still predict the strains with high precision.

### Principle of Strain Estimation



## Dynamics of Extreme Waves and their Interaction with Offshore Structures

### DEWIOS

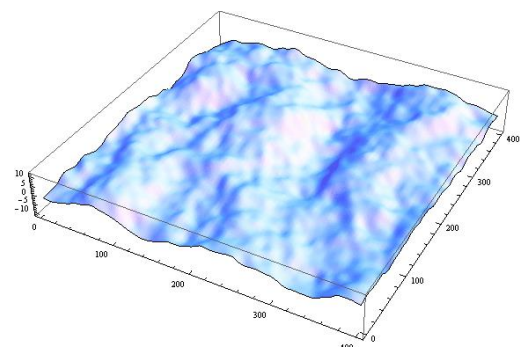
*Erik Damgaard Christensen, Per A. Madsen, and Harry B. Bingham*  
*DTU-MEK, Building 403, Nils Koppels Alle', 2800 Kgs. Lyngby*

Many present and future offshore structures are/will be placed in intermediate water depth (20-60 m). Extreme storm wave events represent a great threat to coastal and offshore structures (e.g. offshore oil platforms, wind turbines etc.). These events will grow in frequency and magnitude given e.g. anticipated increased storminess in Northern Europe due to climate change effects.

The objectives of the project relate to three defined PhD-studies:

#### **Project A: Dynamics and kinematics of extreme non-breaking and breaking irregular waves**

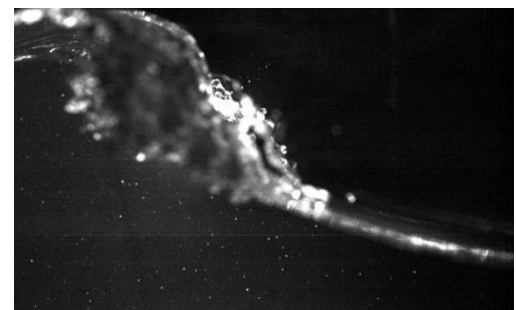
The main objective of project A is to improve the description and calculation of the kinematics of highly nonlinear multidirectional irregular waves. In this connection, one activity will be to develop a new highly accurate and fast numerical spectral model including a new generic module for wave breaking. Another theoretical activity will be to improve conventional perturbation and stretching methods for predicting kinematics in irregular waves.



*Illustration of a multi-directional sea state*

#### **Project B: Detailed analyses of breaking waves and their interaction with offshore structures in intermediate depth**

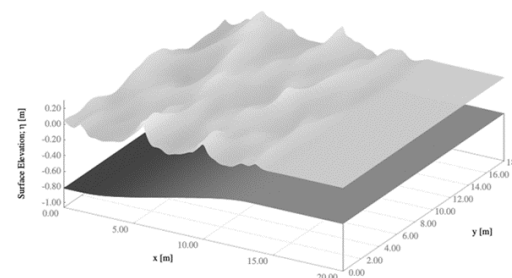
The objective of project B is to develop a model that can represent the air-entrainment in breaking and broken waves. This shall be based on a fast method based on a convection/diffusion approach of the air-content. The implemented model shall study the effect of air-entrainment on the wave kinematics and on the wave loads on offshore structures.



*Photograph of the upper area of a breaking wave indicating the mixture of air and water*

#### **Project C: Development of a potential flow solver including wave-structure interaction**

The objective of project C is to develop a fast potential flow solver that can incorporate wave-structure and wave-bottom interaction. The model will be implemented to run on multiple GPU units using MPI. To account for the structures, a fully nonlinear, immersed boundary method for full 3D shall be implemented. The model will include large-scale integrated effect of breaking waves, for instance based on the other two projects



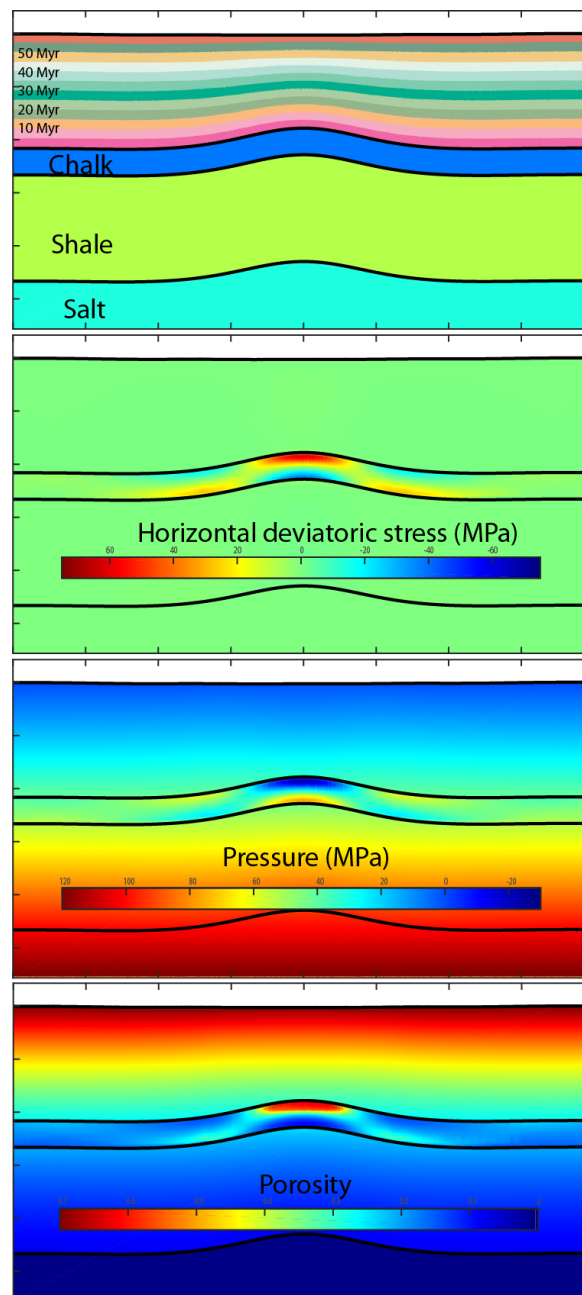
*Transmission of waves over an un-even bottom*

# Danish Hydrocarbon Research and Technology Centre Technology Conference 2017

## High porosity of the Kraka chalk due to compaction-inhibiting flexure

*Kenni Dinesen Petersen, Ole Rønø Clausen, Katrine Juul Andresen, Michael Welch*

Hydrocarbon chalk fields in the North Sea generally have high porosity relative to their depth. We present a physical model of the visco-elastic-plastic Post-Danian evolution of a chalk anticline such as Kraka. Differential loading of the chalk-overburden causes elastic bending of the chalk and 'isostatic' compensation within the Zechstein salt. Elastic bending is associated with local reduction of effective normal stress that inhibits compaction. This can explain porosities of 20-50 % at ~2km depth. The model, supplemented with detailed stratigraphic data and rock mechanical laboratory measurements, can be refined to predict hitherto undiscovered regions of high porosity in the North Sea chalk.



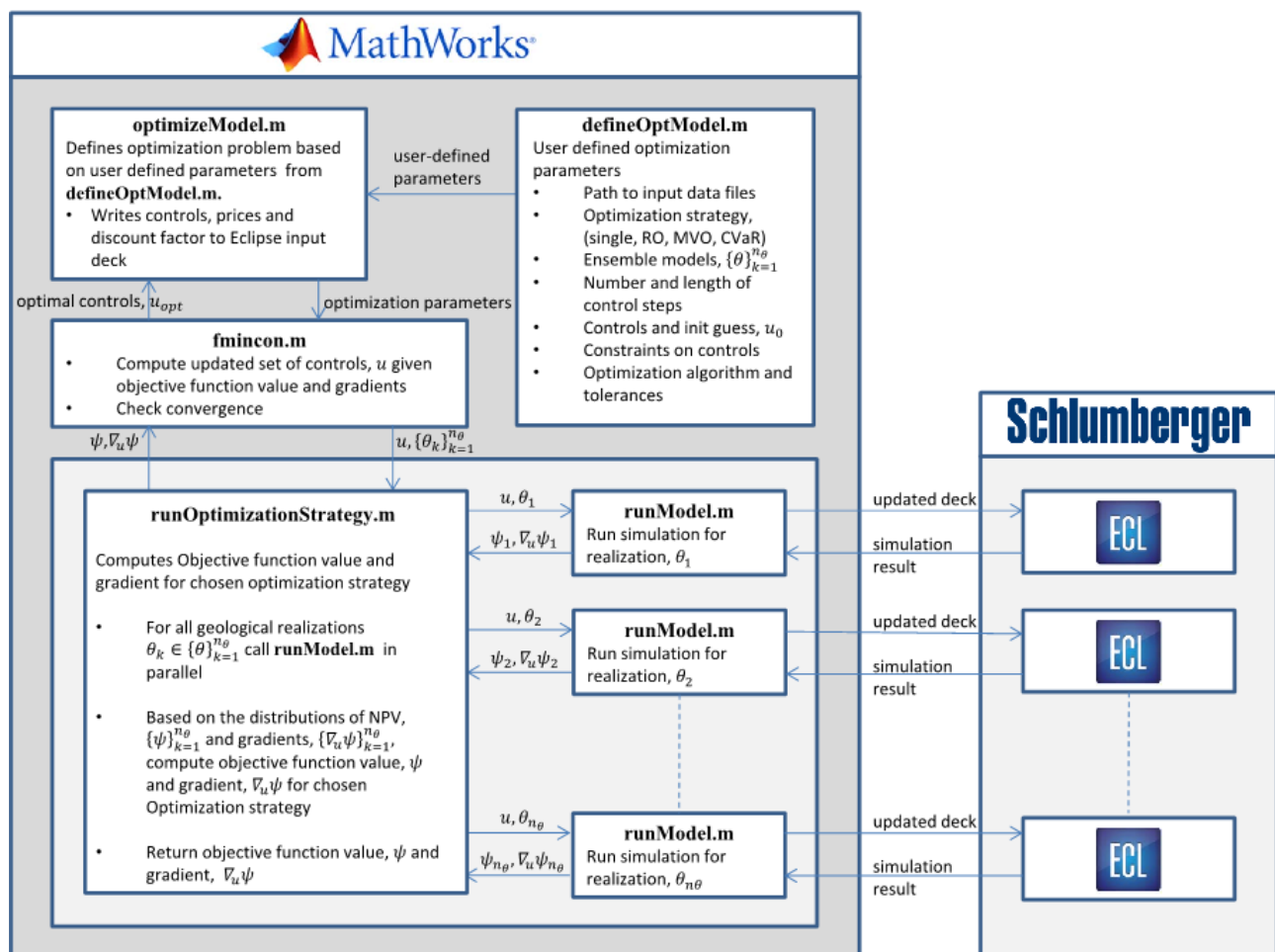


## Oil production optimization of black-oil models

### Oil production optimization of black-oil reservoirs by integration of Matlab and Eclipse E300

Steen Hørsholt, Hamid Nick, John Bagterp Jørgensen

We have developed an optimization software tool that combines the simulation power of a commercial black-oil reservoir simulator (Eclipse E300), with adjoint-gradient capability and state-of-the-art software for constrained optimization (Matlab). The software can apply various optimization strategies on black-oil and other types of reservoir flow models. We consider production optimization strategies, which take the uncertainty of the geological reservoir properties into account in order to mitigate the associated risk. Such strategies include mean-variance optimization, robust optimization and conditional value at risk optimization. Consequently, the optimization software constitutes a powerful tool to assist and guide decision making in the reservoir management process. We present workflow of the optimization software and a numerical example. The example is a case study of mean-variance optimization of water flooding in a synthetic 2-dimensional black-oil reservoir.



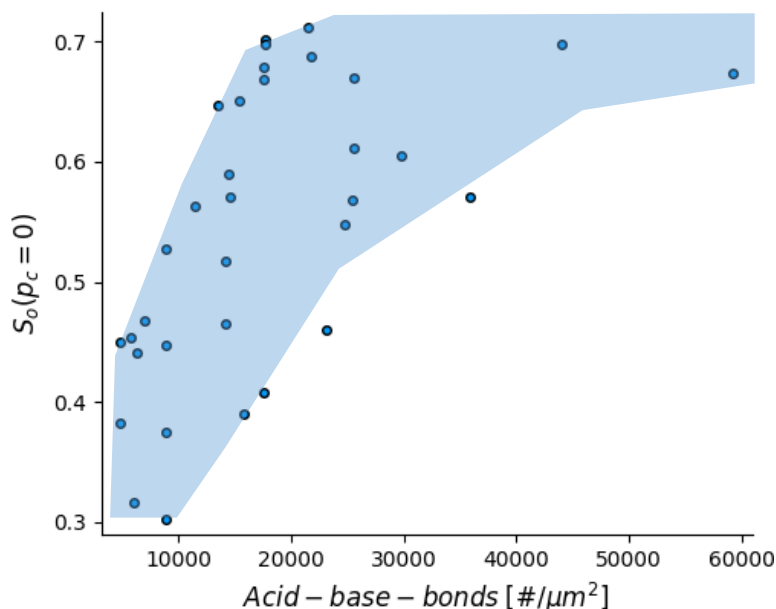


## Thermodynamic analysis of chalk-brine-oil interactions

### Implications for increased recovery of oil from the North Sea chalk reservoirs

*Ali A. Eftekhari, Kaj Thomsen, Erling H. Stenby, Hamidreza M. Nick*

The surface complexation models (SCM) are used successfully for describing the thermodynamic equilibrium between the pure calcite surface (carbonate and calcium sites) and brine solutions. In this work, we show that the model parameters that are reported for the calcite-brine system are not applicable to the natural carbonates. We adjust the SCM reaction equilibrium constants by fitting the model to the zeta potential data that are reported for the pulverized Stevns Klint chalk. Then, we use the model, implemented in PhreeqcRM geochemistry package coupled with a finite volume solver, to predict the breakthrough composition of different ions in the chromatographic experiments on the intact Stevns Klint chalk cores. Again, the model falls short in predicting the reactive transport of brine in a natural carbonate, implying that zeta potential data is not enough for optimizing the SCM model parameters for the reactive transport applications. We propose an optimization procedure that fits the coupled SCM-transport model parameters to the chromatographic (single-phase core flooding) data. The zeta potential measurements are implemented in the optimization scheme as nonlinear constraints. We then use the optimized model to study the thermodynamic equilibrium between the oil and chalk surfaces in presence of different brine compositions, including the dissolution and precipitation of minerals. We represent the chalk-oil interactions by acid-base equilibrium reactions between the calcium and carbonate sites on the chalk surface and carboxylic acids and amine bases on the oil surface, respectively. Comparing the model results to a data set of the spontaneous imbibition experiments for chalk shows that the remaining oil saturation in the imbibition experiments is correlated with the number of bonds between the amine and carboxylate groups on the oil surface and the carbonate and protonated calcium on the chalk surface.



## The Problem of Short-Circuiting in Deformable Fractured Reservoirs

*Saeed Salimzadeh, Hamid M. Nick*

The problem of short-circuiting, in which a short communication path between the injector and producer wells is established, occurs frequently in fractured reservoirs. Fractures, natural or engineered, are a main contributor to the problem. In deformable reservoirs, the mechanical deformation of the matrix due to hydro-thermal loadings as well as chemical reactions of the rock to the flowing fluids contribute to the local aperture variation in the system. The local aperture variation commonly increases the conductivity of the fracture, creating a favorable flow path (Figure 1).

In this study, a finite element model is developed to simulate deformable fractures under thermo-hydro-chemical (THC) loadings during the lifetime of a reservoir. Discrete fractures are modelled as surface discontinuities within 3D matrix. The model is utilized to evaluate the contribution of each process in the problem of short-circuiting.

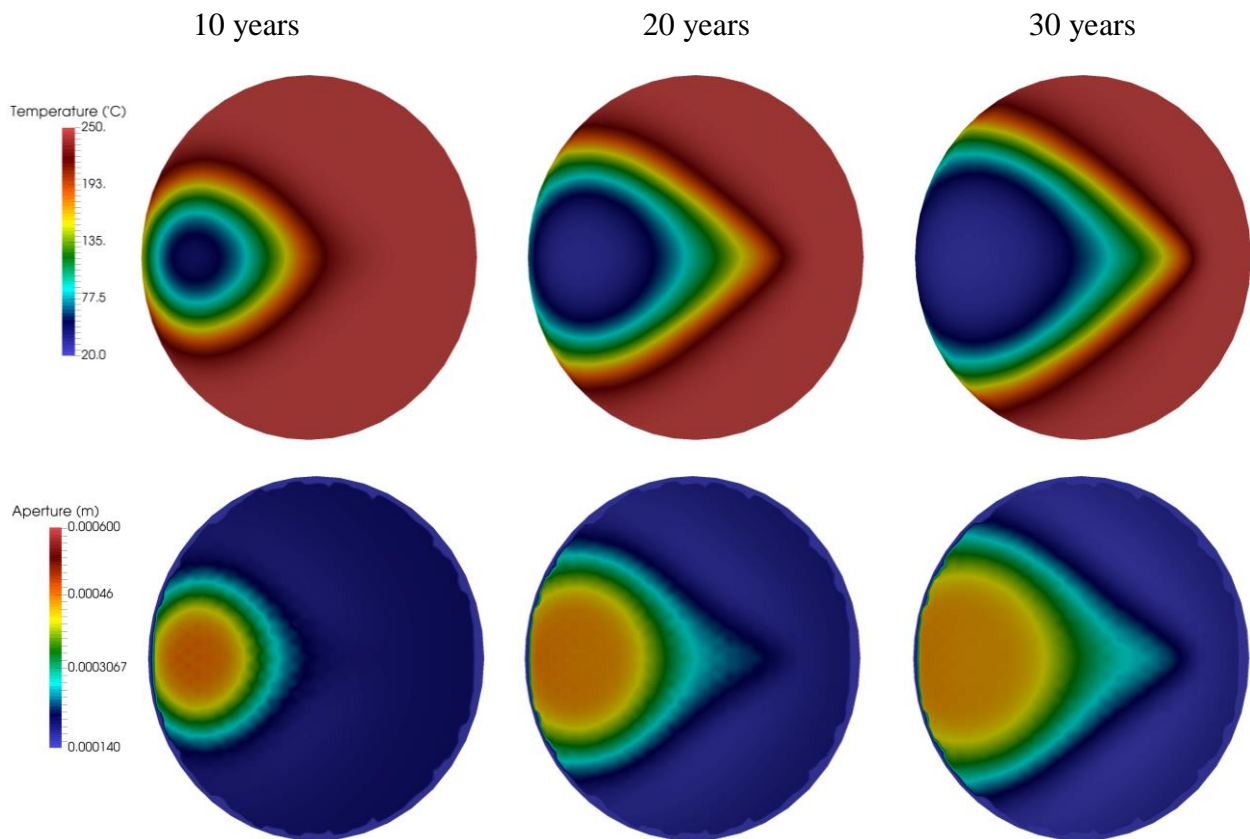


Figure 1- Favorable flow-pathway in a fracture due to the thermal contraction of the rock matrix

# Danish Hydrocarbon Research and Technology Centre Technology Conference 2017

## Understanding controls on fracture geometry using a geomechanical model of fracture propagation

*Michael Welch and Mikael Lüthje*

Fracture prediction and modelling is one area where there is scope for significant technical advance. At present fractures are modelled either by modifying the bulk rock properties to take account of the fracture porosity and permeability, or using stochastically generated Discrete Fracture Network (DFN) models. Both methods tend to give a poor history match because the distribution, orientation, length and connectivity of fractures in the subsurface is not well constrained. We propose to improve the prediction of fluid flow in a fractured reservoir, by developing an algorithm to accurately model the key parameters of a fracture population (fracture density, fracture size distribution, and connectivity) based on the geomechanics of fracture nucleation and propagation, and using this to generate a mechanically-based DFN that more accurately represents the subsurface fracture geometry. We will use a preliminary version of this model to demonstrate some of the key geomechanical controls on fracture geometry, such as fracture propagation rate and strain anisotropy, and illustrate the different types of fracture network that can develop under different conditions.



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## A project on innovation pipeline concepts

*Jens Vinge Nygaard, Department of Engineering, Aarhus University*

*Anne Ladegaard Skov, Associate Professor, Head of Center DPC, DTU Chemical Engineering, Technical University of Denmark*

*Jørgen Gross-Petersen, Danish Hydrocarbon Research and Technology Center, Technical University of Denmark*

Pipelines forms normally part of all offshore hydrocarbon developments and the pipelines often are a significant part of the project development costs. Challenges for the conventional offshore Carbon Steel (CS) welded pipelines are seen as:

Up to 40% of failures in CS pipelines are related to problems with corrosion  
If scale potential exists, CS pipelines are prone to build up scale

The innovative polypropylene pipeline with an added weight coat for on bottom stability is seen as an alternative solution defined in the report Innovative Corrosion Resistant Offshore Pipeline Concept. The project is presently seen as being on a Technical Readiness Level of about (TLR) of 2.

The innovative pipeline have an estimated quantitative cost similar to the costs for a corresponding conventional CS welded pipeline, but the innovative pipeline further advantages versus conventional CS welded pipeline construction in some essential ways:

- The polypropylene pipe is corrosion resistant
- The polypropylene pipe inner surface is much less prone than CS pipe to build up of scale.
- Only elastic bending of the polypropylene pipeline is required, when reeling and the minimum reel diameter required is much smaller than when reeling CS welded pipe
- With the lighter and smaller laying gear required, the pipeline reel laying equipment may be fabricated as modules, suitable for installation on an optimal DP vessel. Reel laying equipment as modules, allows use of a DP vessel for other business when pipeline construction is not economically attractive. A suitable DP vessel may also be contracted for the pipe laying work
- The lead time for an innovative polypropylene pipeline with weight coat is significantly shorter than the lead time for a conventional CS welded pipeline.
- If parallel pipelines are required, these may share a single weight coat and be installed together

The above advantages of the innovative concept is seen very important to achieve for costs similar to a CS welded pipeline. CRA pipelines are available but at costs 2 to 3 times the cost of a CS welded pipeline



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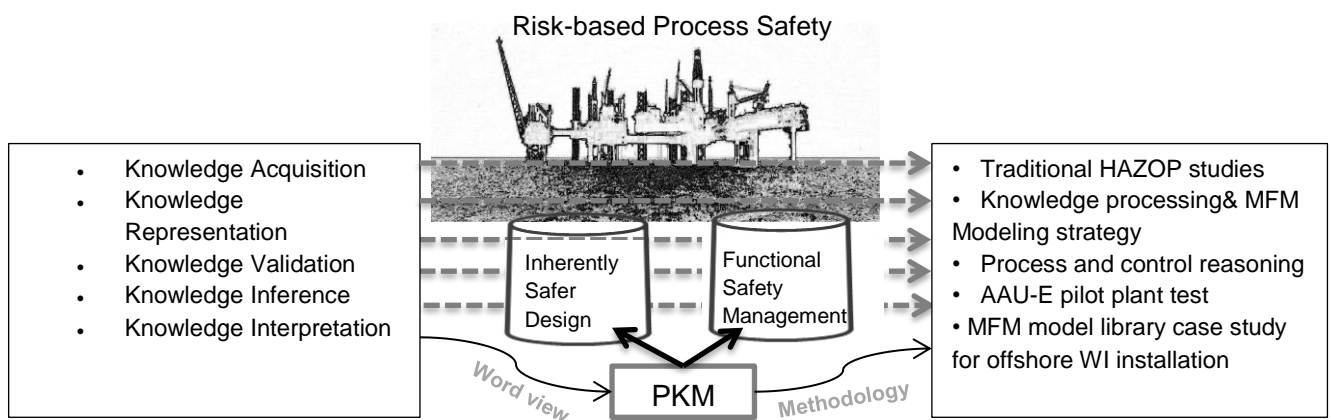
## KNOWLEDGE MANAGEMENT FOR INCREASING WATER INJECTION AVAILABILITY

*Jing Wu, PostDoc, Department of Electrical Engineering, Technical University of Denmark*

Operational performance and process development/design aspects related to facilities is essential for production to decrease down time and in turn the safety compliance of company is paid off as well. Knowledge of its plants and processes is one of the prime assets of a company for boosting operation excellence and reducing the human errors related to incidents, but the management of this asset often appears to be relatively neglected. The purpose of Increase Water Injection Availability project funded by DHRTC is to address this problem on the hypothesis of deploying big data analytics combined with functional and physical modelling for preventing the decline over time in Water Injection (WI) regularity and capacity, with collaborations among DTU Electrical Engineering, DTU Compute, Aalborg University Esbjerg and Eldor. This presentation representing the project group is to give a summary of some results concerning the aspect of functional modeling, i.e. Multilevel flow modelling (MFM) research progress for the purpose. The results are produced by members collectively.

Process knowledge is held within the organization in a variety of forms, including systems and procedures, standards and codes, design manuals and other forms of process documents. Process knowledge management (PKM) is one of elements in both of Risk-based process safety pillars for understanding hazards and operability risk. The acquired knowledge is represented by MFM to serve as a means supporting for operators/managers to understand important features from the original raw data/knowledge. A prerequisite for using MFM for decision support is the availability of a valid model of the plant to be supervised. Ultimately, it can help with decision makings advanced by its reasoning capability.

The results are reported in following aspects: 1) Process knowledge acquisition; 2) Process knowledge transformation and MFM modeling strategies; 3) Process and control reasoning; 4) Validation and verification of MFM model and application on the AAU-E pilot plant; 5) MFM model library case study for offshore WI installation.

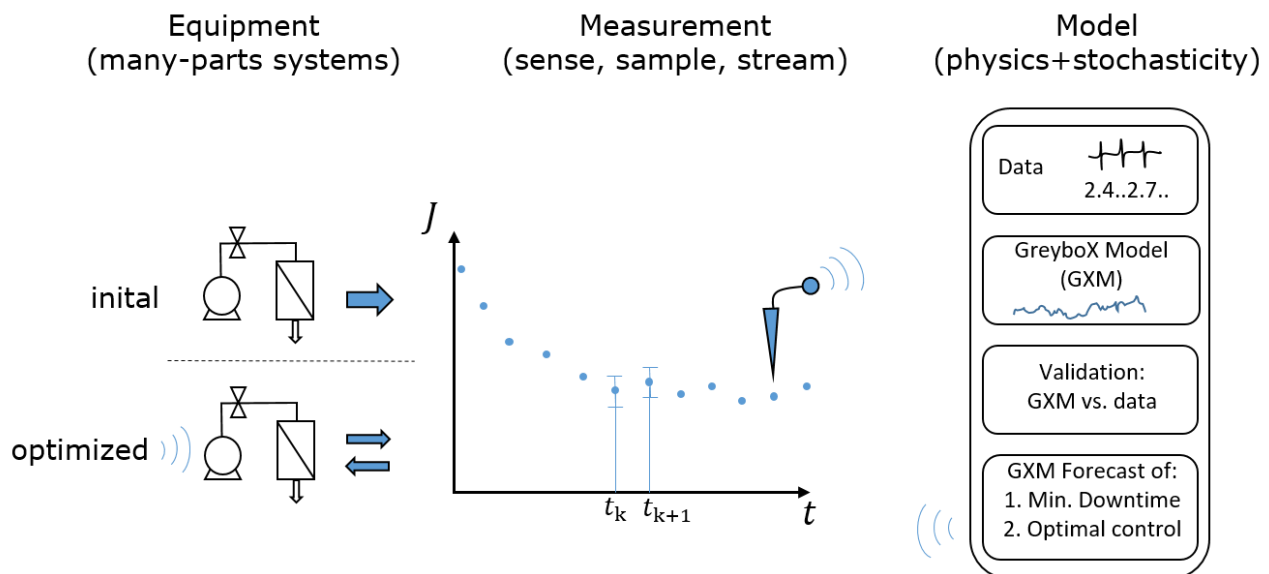


## Physical-Stochastic (Greybox) Modeling and Optimal Control of Membrane Filtration Processes for Use in Oil Recovery Operations

*Goran Goranović, Jan Kloppenborg Møller, Thomas Martini Jørgensen, Henrik Madsen*

Membrane filtration is an environmentally friendly oil-water separation method, but has a low cost-effectiveness in off-shore oil production because of: 1) membrane fouling, 2) frequent need for cleaning, 3) transient-operation instability, and 4) requirements for supervision. Thus, automating and optimizing the overall membrane filtration process - for use at both injection and separation sites - would represent a major milestone for development of reliable, environmentally clean technology, useful particularly for off-shore oil industry.

Here we use the greybox mathematical modeling, involving stochastic differential equations, to formulate physical-stochastic models governing a membrane filtration system. The greybox modeling explicitly accounts for many uncertainties in the physical system. We provide the best model for our filtration unit, and based on it demonstrate a real-time (feed-back) control of the membrane filtration enabling minimal energy consumption.



# Danish Hydrocarbon Research and Technology Centre Technology Conference 2017

## Grey-Box Modeling of an Offshore Deoiling Hydrocyclone System

*Mads V. Bram, Leif Hansen, Dennis S. Hansen, and Zhenyu Yang*

The increasing water cut from offshore production wells render optimization of the deoiling process vital for continuous oil and gas production. Hydrocyclones are commonly used as the last stage of the deoiling process and must therefore keep the oil content in the produced water below 30ppm to comply with the local legislation. Optimizing the performance of hydrocyclones is a balance between separation efficiency and reject flow rate. Thus, it is essential to exploit the freedom within the system which may be found by means of analyzing the internal fluid mechanics of the hydrocyclones. This work investigates the establishment of a control-oriented grey-box model of a hydrocyclone as an extension of a previously defined droplet trajectory-based model. The model parameters were estimated using numerical optimization by fitting the model outputs to experimental data. This work proposes a method to estimate how the hydrocyclone pressures are related to its flow rates by means of virtual orifice equations. The experimental results prove that the proposed model is able to estimate the relationship between pressures and flow rates with good accuracy and can be extended in future works to include dynamic properties.



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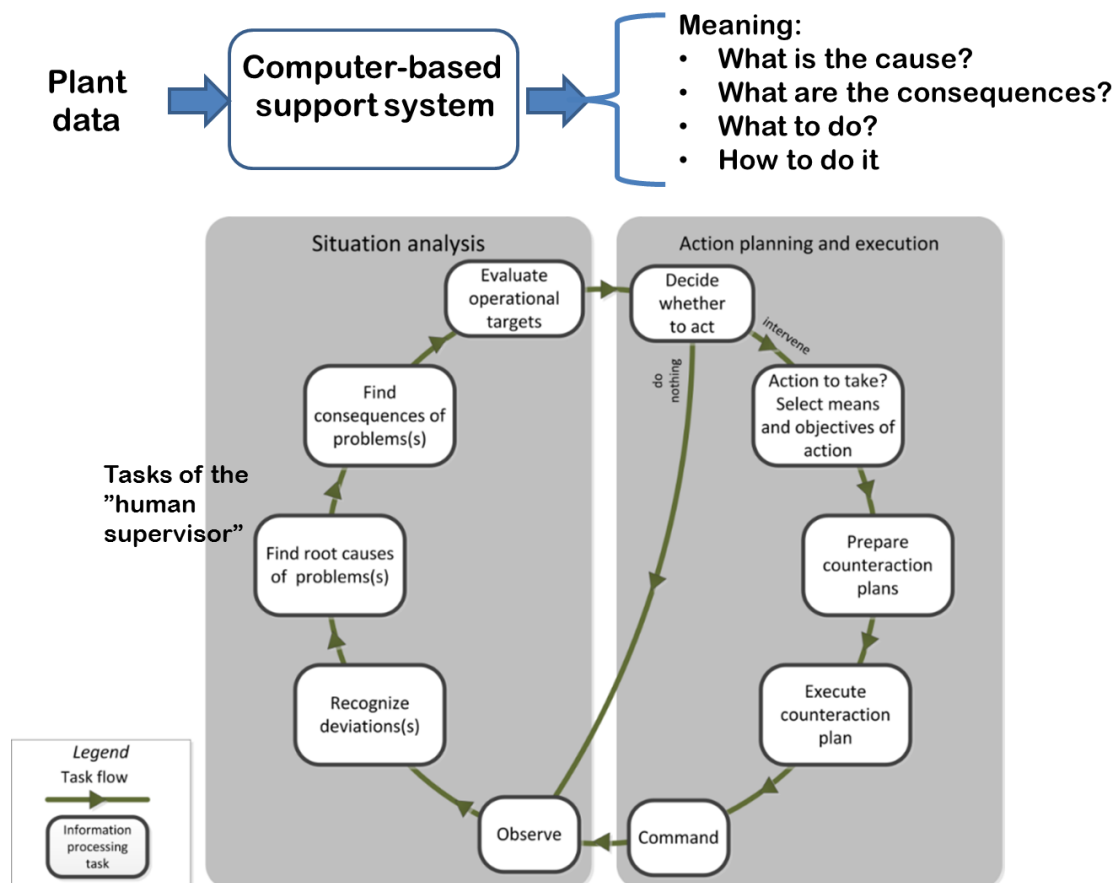
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## Pilot Demonstration of Alarm Management in Oil & Gas Operations.

### - Decision Support from Functional Modelling.

*Thomas Martini Jørgensen, Morten Lind, Bjarne André Asheim, Zhenyu Yang, and Erik Bek-Pedersen*

The Cost Transformation program of Danish Hydrocarbon Research and Technology Centre (DHRTC) is focused on the improvement of plant performance by minimizing downtime and lowering risks in the context of operations for oil and gas. Specifically a consortium has been established to develop a decision support system that integrates functional modeling (MFM), advanced process control and data analytics. A major aim is to mature the so-called Multilevel Functional Modelling theory and develop a suitable way to implement it in an industrial prototype solution. Here we report the results of our first prototype of functional modeling applied to specific process scenarios implemented at a Pilot Plant hosted by Aalborg University in Esbjerg. This presentation will explain the high level purpose of the project and the learnings from the first tests.







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